AMR sensor element for angle measurement

The invention relates to a magnetoresistive angle sensor comprising a sensor device for detecting an angle α of an external magnetic field relative to a reference axis of the sensor device.

Magnetoresistive sensors are usually used to detect angles in motor vehicle technology in order, *inter alia*, to monitor and control the position of a pedal or the position of a throttle. In this case, a magnetoresistive angle sensor usually consists of two Wheatstone bridges which are offset by 45° with respect to one another, said bridges being exposed to an external magnetic field. The two bridges respectively supply, as a function of an angle α of the external magnetic field relative to a reference axis of the sensor or of the sensor device formed by the bridges, angle-dependent voltage output signals which can be shown in a manner known to the person skilled in the art using the following relation:

$$U_1 = U_0 \sin(2\alpha)$$

$$U_2 = U_0 \cos(2\alpha)$$

Here, U_1 and U_2 are the voltage output signals of the two bridges, U_0 is the voltage amplitude of the output signal, which depends *inter alia* on the ambient temperature, and α is the angle of the external magnetic field relative to the reference axis of the sensor device.

The angle α of the external magnetic field relative to the sensor or to the bridges is calculated from these output signals, for example using the CORDIC algorithm. In order to implement this algorithm, the analog output signals of the bridges must be converted into digital signals by means of an analog/digital converter.

The angle α of the external magnetic field relative to the sensor is then determined using the likewise known relation:

$$\alpha = ½ \arctan(U_1/U_2) = ½ \arctan(\sin(2\alpha)/\cos(2\alpha))$$

for example using digital signal processing means suitable for this purpose. Taking account of the sign of the output voltage U_2, the angle α can be calculated with extremely high accuracy using the arctan function over 180°.

The Wheatstone bridges for forming a sensor device are usually designed in the form of resistors arranged in a meandering manner in an AMR layer. One disadvantage here is that relatively great offset signals are generated on account of manufacturing tolerances during etching of the meandering resistor structures, and these offset signals are included directly in the angle measurement as errors. Particularly at the edges of the meandering structures, undercuts may be produced which cause a strong offset signal. When evaluating the output signals obtained from the bridges, this offset has to be taken into account by means of a technically complex evaluation unit.

It is an object of the invention to specify a magnetoresistive angle sensor which on account of its design has a considerably smaller offset signal and thus allows more accurate measurements, wherein the output signal can be fed directly for evaluation. This object is achieved by the features specified in claim 1.

The core concept of the invention is that the plurality of meandering resistors of a Wheatstone bridge are replaced by a single, continuous and flat AMR layer, wherein the AMR layer has one electrical contact for applying a current. Furthermore, a plurality of electrical contacts are formed on the AMR layer in order to be able to detect a flow of current from the aforementioned electrical contact in each case to one of the plurality of electrical contacts. This makes use of the fact that, when an external magnetic field is applied, the AMR has its greatest electrical resistance in the direction in which an external field is being applied. Accordingly, it has its lowest resistance perpendicular to this direction of the external magnetic field. Therefore, by determining the flows of current between the plurality of electrical contacts and the one electrical contact for supplying an electrical current, the direction of the external magnetic field relative to the AMR layer can be determined by determining that contact through which the least current flows.

The outer shape of the AMR layer may essentially be selected at will. It is preferably designed in the manner described below. The number of electrical contacts for measuring a flow of current may also essentially be selected at will, and in theory an unlimited number of electrical contacts may be provided. The distance of the plurality of electrical contacts from the one electrical contact for applying a current must be selected to

be great enough to achieve a sufficient flow of current perpendicular to the direction of an external magnetic field.

The advantage of the invention consists in that, by virtue of the flat design of the magnetoresistive AMR layer, undercuts at the edge of the AMR layer have virtually no effect on the measurement result since the length of the edge compared to the surface area of the AMR layer is significantly smaller than in the case of the known meandering structures of a Wheatstone bridge. As a result, the output signals are virtually no longer falsified or provided with an offset signal.

Advantageous developments of the invention are characterized in the dependent claims.

The development of the AMR layer as specified in claim 2 means that the sensor device is designed to be symmetrical in relation to all possible orientations of the external magnetic field. The sensor device or the magnetoresistive angle sensor equipped therewith can thus detect any angle between the external magnetic field and the circular AMR layer.

Advantageously, in a circular AMR layer, the electrical contact for applying a current is arranged in the center of the circular AMR layer, as specified in claim 3. A symmetrical design of the sensor device formed in this way is thereby achieved, wherein the magnetic flux flowing through the AMR layer, particularly when there are further electrical contacts arranged at the edge of the circular AMR layer as claimed in claim 4, respectively passes through an equal-length path of the AMR layer from the central contact to the edge contacts, regardless of the orientation of the external magnetic field. In this case, the plurality of electrical contacts at the edge are preferably arranged so that they are distributed equidistantly around the edge. In one advantageous development, eight electrical contacts are provided at the edge. This allows a sufficiently precise resolution of the angle between the external magnetic field and an imaginary reference axis of the sensor device by extrapolating the measurement results. On account of the 180° periodicity of the AMR layer over the angle of the external magnetic field, it is particularly advantageous to add the current flowing through in each case two opposite edge contacts in order in this way to obtain four difference current signals. A first current signal is obtained by the currents flowing through the edge contacts 1 and 5, a second current signal is obtained by the currents flowing through the contacts 2 and 6, a third current signal is obtained by the currents flowing through the contacts 3 and 7 and a fourth current signal is obtained by the currents flowing through the contacts 4 and 8. If the third difference current signal is subtracted from the first difference

current signal and the fourth difference current signal is subtracted from the second difference current signal, two further current signals are obtained which, viewed over a 360° angular range, in each case have a sine or cosine form corresponding to the output voltages of a known Wheatstone bridge. The angle α between an external magnetic field and the sensor device can be deduced from these signals in a likewise known manner.

In one alternative development, which is specified in claim 5, the AMR layer is designed to be essentially semicircular. As a result it is possible in particular to reduce the size of the sensor device, since only half the surface area of a full circle as described above is required. A semicircular design of the AMR layer is sufficient since, as mentioned above, the AMR layer has 180° periodicity in relation to the external magnetic field.

According to the development of the AMR layer as specified in claim 6, when it is designed in a semicircular manner the electrical contact for applying a current is once again arranged in the center of the associated full circle or in the center of the straight side of the semicircle of the semicircular AMR layer.

Furthermore, as specified in claim 7, it is proposed that a plurality of electrical contacts be arranged at the edge of the semicircular AMR layer, in particular five electrical contacts, which are arranged at the semicircular edge of the layer and are distributed equidistantly with respect to one another. A sufficient resolution of the angle between the external magnetic field and the sensor device is thus possible. The above-described sine and cosine signals are in this case obtained by adding the current present across the first and fifth contacts minus the current present across the third contact or by subtracting the current present across the fourth contact from the current present across the second contact.

In order to improve the measurement accuracy of the magnetoresistive angle sensor, it is proposed in claim 8 that the plurality of electrical contacts be placed at the same potential in order to avoid affecting the current intensities measured at the contacts. In particular, all the electrical contacts are placed at ground potential so that no fault currents flow and no error voltages are present.

Simple manufacture of the AMR layer by the person skilled in the art is made possible by virtue of a development specified in claim 9. Applying a Permalloy layer to a silicon support substrate and providing said Permalloy layer with electrical contacts can be carried out by the person skilled in the art, wherein, by virtue of the above-described developments of the AMR layer, any undercuts of the Permalloy layer which occur at the edge of the AMR layer during manufacture are of virtually no consequence and thus the measurement results of the sensor are not falsified.

It will be understood that such sensors can be used in all fields of technology in which it is desired to measure an angle of a rotating object. Advantageously, however, such sensors are used in motor vehicle technology, as specified in claim 10, in order in particular to monitor and control the position of a pedal and/or the position of a throttle so as to regulate the power of an engine. The angular resolution of the angle between the external magnetic field and the sensor that can be achieved with such sensors is sufficient for applications in motor vehicle technology.

The invention will be further described with reference to two examples of embodiments shown in the drawings to which, however, the invention is not restricted.

Fig. 1 shows an AMR angle sensor from the prior art.

Fig. 2 shows the calculated angle α of this sensor.

Fig. 3 shows a circular AMR sensor.

Fig. 4 shows current signals of this sensor.

Fig. 5 shows a semicircular AMR sensor.

Fig. 6 shows current signals of this sensor.

The AMR angle sensor 10 shown in Fig. 1 consists essentially of two Wheatstone bridges 11, 12 which are offset by 45° with respect to one another and are each composed of four meandering resistors 13. If this AMR angle sensor 10 is passed through by an external magnetic field, in each case an output voltage $U_1 = U_0\sin(2\alpha)$, $U_2 = U_0\cos(2\alpha)$ will be induced in a known manner at the two Wheatstone bridges 11, 12, wherein the angle α between the external magnetic field and the AMR angle sensor 10 or a reference axis in the AMR angle sensor 10 can be determined from these output voltages using the known CORDIC algorithm, as shown in Fig. 2.

Fig. 3 shows a magnetoresistive angle sensor 100 which essentially consists of a circular AMR layer 14, preferably a Permalloy layer on a silicon support substrate. Arranged in the center is a current contact K_0, through which a current I is passed into the AMR layer 14. Eight contacts K_1 to K_8 are arranged at the edge, distributed equidistantly around the circumference of the circular AMR layer 14, in order in each case to measure a flow of current between the central contact K_0 and an edge contact K_i. By virtue of the 180° periodicity of the AMR layer 14 over the angle of the external magnetic field, the currents

flowing through the opposite contacts can be added in order in this way to obtain four current signals:

$I_1=IK_1+IK_5$

$I_2=IK_2+IK_6$

$I_3=IK_3+IK_7$

$I_4=IK_4+IK_8$.

If I_3 is subtracted from I_1 and I_4 is subtracted from I_2, two new difference signals are obtained which each have the desired sine or cosine form over 360°, as shown in Fig. 4. Using the CORDIC algorithm known per se, the connection (shown in Fig. 2) between the angle α and the external magnetic field can in turn be calculated from these difference signals.

The alternative embodiment shown in Fig. 5 allows the magnetoresistive angle sensor 100 to be miniaturized since the semicircular AMR layer 15 takes up less space than a full-circle AMR layer 14. In this case, five contacts K_1 to K_5 are arranged in an equidistantly distributed manner around the semicircular edge of the AMR layer 15, in order in each case to obtain a flow of current between these contacts K_i and the contact K_0 arranged in the center of the straight edge of the AMR layer 15. The above-described sine or cosine signals are then obtained by adding or subtracting the various signals as follows:

$I_1=IK_1+IK_5-IK_3$

$I_2=IK_2-IK_4$.

From these difference signals shown in Fig. 6 it is possible, again using the known CORDIC algorithm, to obtain the form of the angle α over 360° which is shown in Fig. 2.

The above-described operations can be carried out using electronic components known to the person skilled in the art.

LIST OF REFERENCES:

100	magnetoresistive angle sensor
10	AMR angle sensor (prior art)
11	Wheatstone bridge
12	Wheatstone bridge
13	meandering resistor
14	circular AMR layer
15	semicircular AMR layer
K_0	central current contact
K_i	edge current contact, $i = 1$ to 8
α	angle between a magnetic field and a sensor device
I	current intensity
U	voltage